Putting “mobile” into mathematics

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Putting the "mobile" into mathematics: Results of a randomised controlled trial

Abstract

There is an increasing use of mobile technologies in the classroom, particularly its use in supporting contextual learning, but comparative research on the effects of mobile learning in mathematics are few. The aim of this research was to examine student perceptions of using mobile technologies and their effect on mathematics achievement in a randomised controlled trial. Seventy-four Grade 5 and 6 students and three teachers participated in the study. Both groups participated in six weeks of active and collaborative learning activities on math. The experimental group used tablets to support them in their activities while the control group had similarly designed activities without the tablets. The tablets were observed to have facilitated constructivist learning activities as students moved in and out of different learning contexts. Most of the experimental group had positive evaluations but their end activity ratings were not significantly different from the control group. There was also no difference found in the groups' post-test achievement scores following an analysis of covariance with pre-test as covariate. For items relating to student misconception, students in the experimental group performed better. Overall, the study highlights that the success of a mobile learning intervention is dependent on various factors, such as student characteristics, stability of the technology and content compatibility. Implications for practice and future researchers are discussed.

Keywords: mobile learning; mathematics education; student perceptions; technology-enhanced learning; mathematics achievement

Highlights:

1. The study was randomised controlled trial using an integrated framework of micro, meso and macro evaluation.
2. The experimental and control groups had very similar activities, one mobile and one not.
3. The mobile learning activities were either *augmentation* and *modification* in the SAMR framework.
4. Most students were positive about the mobile learning activities but their ratings were not significantly different from the control group.
5. No group differences were found in student achievement scores. However, the experimental group performed better on misconceptions re angles.
6. The mobile devices supported students in collaborative learning activities as they moved in and out of different learning spaces.

1. Introduction

There are several issues surrounding mathematics education, among which are negative student attitudes, problems with student engagement and achievement. A recent report on Making Maths Count (Scottish Government, 2016) started with the admission that "Too many of us are happy to label ourselves as *no good with numbers*" (p.3). Negative attitudes to mathematics and students' own perception of their ability to do mathematics are linked to student perceptions of the learning environment (Fast et al., 2010), motivation (Hannula et al., 2016) and engagement (Linnenbrink and Pintrich, 2003), which consequently affects math performance. It is thus important to employ strategies that encourage students to engage fully and positively in learning mathematics.

Technology enhanced learning is one of the strategies employed to engage students with mathematics. The National Council of Teachers of Mathematics (2000) considered technology as "essential in teaching and learning mathematics" (p. 3). However, technology use must not just be for technology's sake. It must be guided by a rationale to promote transformative learning in the classroom (Puentadura, 2006). Carpenter and Lehrer (1999) outlined mathematical activities that promoted understanding: constructing relationships, extending and applying mathematical knowledge, reflecting about experiences, articulating what one knows, and making mathematical knowledge one's own. On the other hand, the potential benefits of using mobile technologies for learning include: facilitating learning across contexts, facilitating contextual learning, and providing personalisation in both personal and collaborative environments (Cochrane, 2010). These potentials make mobile technology seem an ideal tool for learning mathematics.

Hirsh-Pasek et al. (2015) suggest that students learn best when they are engaged in meaningful and socially interactive learning experiences. Previous studies on mobile learning for math have shown that it facilitates engagement (Baya'a and Daher, 2009), contextualises mathematics learning (Tangney et al., 2010), supports collaboration (Zurita and Nussbaum, 2004) and facilitates new ways to visualise abstract math concepts in the real world (Spikol and Eliason, 2010). These findings are promising, but studies on math and mobile learning are few.

Furthermore, the research methodology adopted by mobile learning studies tends to focus on interviews, surveys or observation. Only a few studies undertook comparative studies (Sharples, 2013). In studies that used outdoor settings, these narratives and observations provided evidence of high student engagement, but evidence of student achievement was not explored, or in cases where it was explored, the implementation integrity narratives were not present (Kurti, Spikol, Milrad, 2008; Huang, Wu, Chen, Yang and Huang, 2012). In addressing this gap, the current study employed an integrated framework that allowed for different levels of evaluation, focusing on various aspects of mobile technology use. Very few mobile learning studies so far are randomised controlled trials or studies that utilise control groups that follow similar activities. Using an integrated evaluation framework, the current study takes a critical-analytical approach to evaluating mobile learning.

1.1 Theoretical background

Mobile learning, being a relatively new field, is short on theory in the same way that elearning theories had been sparse during the first decade of its introduction into schools. Mayes and De Freitas (2004) noted that “there are really no models of e-learning per se – only e-enhancements of models of learning (p. 4)” and this is at present the same for mobile learning theories. However, constructivist learning is a dominant theory in the mathematics education research community (Dewey, 2011; Piaget, 1951; Vygotsky, 1978; Li and Ma, 2010). Its application to mobile learning literature is just as prominent. Mobile technologies support constructivist learning through active learning activities (Tangney et al., 2010), immersion in authentic environments (Sommerauer and Müller, 2014), and learner-generated context (Bray and Tangney 2016).

Another issue in mobile learning research is the context and setting of the learning environment. For example, Frohberg, Göth, and Schwabe's (2009) review of state-of-the-art mobile learning studies included mobile learning activities in both formal and informal learning environments, including museums, rivers, forests, towns, and so on. These rich contexts facilitated several studies designed within the situated learning framework (Kurti et al., 2008; Sommerauer and Müller, 2014). Situated learning theories emphasise that knowledge and cognition cannot be separated from context and call for authentic learning environments (Lave and Wenger, 1991). In computer based learning environments, some examples of applications of this framework are in microworlds, virtual reality, and simulations (Herrington and Oliver, 1995). Of course, microworlds are not “real world” either, and by the process of abstraction and simulation the authenticity of the environment is compromised. In mobile learning environments, these representations move to the real world. Mobile devices can capture data from the environment with built-in sensors, camera and communication tools and these features help facilitate learning activities designed within the situated learning framework, allowing learning to take place in an authentic context. For example, in Tangney et al.’s (2010) study of mobile learning activities based on the Realistic Mathematics Education principle, one of the activities used the mobile device to measure the height of an object, and in this instance the technology use was situated within the problem that the students were trying to work out and was therefore authentic.

One of the frameworks used to understand how technology is integrated in the classroom is the SAMR Model (Puentadura, 2006). The framework categorises the level of technology adoption into substitution, augmentation, modification, and redefinition. A diagram of this model is shown in Figure 1. The first two levels show how learning technologies can be used to enhance learning activities, while the latter two show how technologies can transform the learning tasks. This model, while not specifically created for mobile learning, has been used in several mobile learning studies (Burden, Hopkins, Male, Martin, and Trala, 2012; Authors, 2014; Romrell, Kidder, and Wood, 2014) and has been a useful reflection tool to gauge how technologies add value to non-technology based learning activities. This framework will later be used to categorise the different activities used in this study.

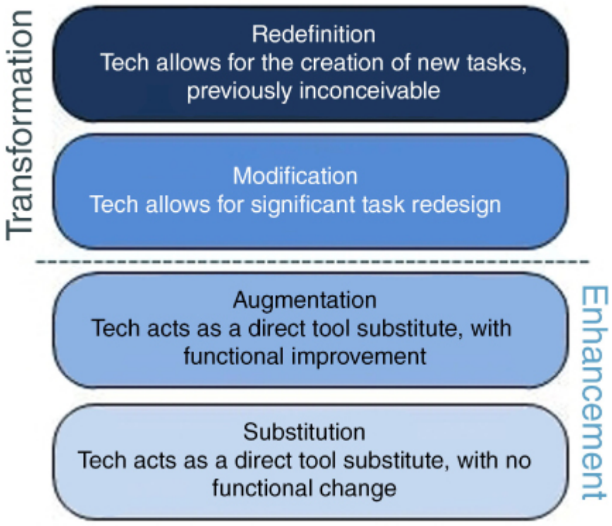

Figure 1. *SAMR model of technology integration (Puentadura, 2006)*

1.2 Student views of mobile learning

Early mobile learning studies tend to focus on user acceptance. Hwang and Tsai (2011) in their review of mobile learning studies between 2001 to 2010 found that majority of the studies focused on student perceptions of mobile use. Technology acceptance models built on these studies in their effort to understand how and why users came to use technology. Davis's (1989) Technology Acceptance Model (TAM) focuses on two constructs that could explain and predict technology use: perceived usefulness and perceived ease of use. Davis’s model notes that users tend to use technology they consider useful (perceived usefulness), but this belief must be coupled with the perception that the benefits will outweigh the effort of using the technology (perceived ease of use). These two constructs provide a direct link to usability evaluation (Morris and Dillon, 1997). Davis believes these perceptions about usability affect the users' attitudes towards technology and consequently their intention to use it.

A systematic review of mobile learning studies on student perceptions found the majority of the studies reported positive student attitudes and enjoyment with mobile learning experiences (Pollara and Brousard, 2011). This was also true for a systematic review of math and mobile learning studies (Authors, 2016). Reasons for students liking the mobile-based maths activities were in three categories: student satisfaction due to technology use (Kim, 2011), student satisfaction due to the changed pedagogy enabled by the technology (Baya'a and Daher, 2009; Zurita and Nussbaum, 2004), and student satisfaction with their own performance (Kong, 2012). Very few studies have discussed negative student perceptions, but in studies that covered these, some negative perceptions emerged from technology issues and the usefulness of the device to facilitate learning math (Liu, 2007; Perry and Steck, 2015).

Studies that looked at student perceptions can be linked to the TAM (Davis, 1989). Bray and Tangney (2016) note that it is the transformative use of technology that makes an impact on students' attitudes to using technology for learning maths. This links to the TAM, wherein perceived usefulness (PU) affects attitudes towards technology (Chang, Yan and Tseng, 2012). In the same way, the negative perceptions about technology emerged from technical issues regarding using technology (Perry and Steck, 2015) and links back to TAM's notion of perceived ease of use (PEOU) and its effect on attitudes towards technology.

1.3 Mathematics achievement in mobile learning environments

The literature has many primary studies on the effects of technology in mathematics achievement/performance, varying with the type of technology use and pedagogy (e.g., Slavin, Lake, and Groff, 2009). However, studies that focus on student outcomes in the use of mobile devices are few. Systematic reviews of maths and mobile learning have identified that more studies reported positive learning outcomes (Crompton and Burke, 2015; Authors (2016); Bano, Zowghi, Kearney, Schuck and Aubusson, 2018). However, as with any other systematic reviews, publication bias might lead to studies with negative findings not being published. While there are more studies that report positive findings, there are studies that found negative results even where the same strategy in adopting technology was used. For example, Miller and Robertson's (2011) randomised controlled trial of game-based learning strategy found no significant difference between the math scores of the control group and experimental group, while Main and O'Rourke's (2011) quasi-experimental study that used the same strategy saw better improvement in the experimental groups' test scores. Similarly, Perry and Steck (2015) used a constructivist approach to learning geometry using a dynamic geometry application found a decline in performance, while other studies that used dynamic geometry systems found positive results (Crompton, 2015). This shows that the use of mobile learning strategies does not always yield positive results and even similar strategies can result in different outcomes. The nature of the intervention, the study design, the participants, and the technology are among the many factors that affect the success of the program.

1.4 The present study

One of the advantages of mobile learning is its capacity to support learners as they move in and out of different learning contexts. As previously noted, a criticism of earlier mobile learning literature is that it is mostly in the form of attitude surveys, interviews or observations, with only a few attempts to carry out comparative evaluations (Sharples, 2013); but this is still the case in a more recent systematic review (Crompton, Burke, Gregory, 2017). Studies on math have covered student perceptions, engagement and achievement, but have done so separately. In a previous version of the current study, Authors (2018) considered these learning outcomes together with a quasi-experimental approach. The current study implemented a randomized controlled trial design with a new set of student cohorts. We examined students' perception of mobile learning as well as achievement, using the Micro Meso and Macro (M3) evaluation framework (Vavoula and Sharples, 2009). M3 provides a structured format to assess usability, educational and organisational impact and their inter-relationships (ibid. p. 12) in three evaluation processes of micro-level evaluation, meso-level evaluation and macro-level evaluation. At micro level, the focus is on the individual activities and the use of technology; at meso level, the focus is on the learning experience using mobile technologies; at macro level, the focus is on the impact of using mobile technologies on students' attitudes towards mathematics and their performance. The two specific research questions this study addressed are as follows:

a) What are the students' views on the use of mobile technology for learning mathematics?
b) Is there an improvement in mathematics achievement when using mobile-supported math learning activities?

2. Method

2.1 Participants

The participants were obtained by soliciting volunteer teachers from within one school district (local authority) in Scotland. Three teachers who co-teached Grade 5 and 6 mathematics from the same primary school agreed to participate and their students also became participants. Two teachers (the Grade 5/6 teacher and the Grade 6 teacher) were assigned to the control group while the Grade 5 teacher and a teaching assistant were assigned to the experimental group. Seventy-four students were randomly assigned by the teachers to the experimental (n=35) and control (n=39) group. The school had 20% of students receiving free school meals, around 8% less than Scotland's national average. Pupil absences were roughly 5% higher than the national average of 3.8% (Education Scotland, 2015).

2.2 The learning activities

The activities carried out are listed in Table 1. All the activities were carried out in pairs. While Table 1 refers to the individual activity with the mobile device, in all lessons the structure was: (1) a discussion at the start of the lesson that covered an overview of the topic being investigated; (2) an overview of the mobile learning task and a tutorial on how to use the application; (3) the mobile learning activity; (4) a discussion of the artefacts created with the application.

The objective of the mobile learning activities carried out in these sessions was to provide a link between abstract math concepts and their concrete representations in the real world. The lessons were also delivered together with activities that were more aligned with typical classroom activities (for example, the design of symmetrical patterns in Session 2, the angle estimation game in Session 4 and use of manipulatives in Sessions 5 and 7). The mobile device facilitated the learning activities from the less formal and more active activities carried out outside the classroom to the more formal and structured activities done in class. Table 1 also outlines how the activities fall within the substitution, augmentation, modification and redefinition (SAMR) hierarchy (Puentadura, 2006). Control group activities are also listed.

Table 1.

Summary of learning activities mapped into SAMR (Puentadura, 2006) framework

Session	Mobile Learning Activity	Learning Activity (Control Group)	SAMR Framework
Session 1 and 2 Symmetry	**Session 1 and Session 2a.** Using Skitch, students took pictures of symmetrical objects and annotated it with its line of symmetry.	**Session 1 and Session 2a.** Students identified the lines of symmetry of everyday objects.	Session 1 and the first part of Session 2 can be classified as *modification* under the SAMR framework. The mobile device afforded the students to capture artefacts from their environment which they were able to discuss later in class.
	Session 2b. Using Pixel touch, they also created designs that are symmetrical.	**Session 2b**. Using gridded paper, students created designs that are symmetrical.	The second part of the *augmentation* activity in Session 2 falls under. The mobile learning application facilitated an easier process of designing the symmetrical design through its functionality. The undo/redo button also afforded the students to be flexible in their design.
Session 3 and 4 Angles	Students took pictures of objects that corresponded to certain types of angles. They annotated the pictures (using Skitch) to show the angle and its estimated angle measurement. In the next session, using pictures that they had taken the previous week, they used Material Protractor to measure the angles. This was followed by a teacher guided activity to investigate common misconceptions on angles.	Students work in pairs and look for different types of angles in their environment. They then sketch/draw the objects they found in the worksheet provided. In the next session, students used a folded circle as a manipulative to estimate angles. As a class activity, the teacher discussed with the students' misconceptions on angles using pictures of everyday objects and a protractor to measure the angle measurements of these objects.	As described in the control group activity, the activities could be carried out without the use of the mobile device; however, the technology in this instance mediated the activity better as it allowed the students to continue their investigations outdoors to the investigations that they did relating to misconceptions on angle. As such, this activity can be classified at the level of *modification* in the SAMR model.

Session	Mobile Learning Activity	Learning Activity (Control Group)	SAMR Framework
Session 5 and 6- Area and Perimeter	Students investigated area and perimeter of surrounding environment using Measure Map. They investigated properties of area and perimeter using a manipulative and completed task cards that contain word problems on area/perimeter tagged with visual representation using augmented reality.	Students investigate area and perimeter and their relationship using the worksheet provided. They also completed task cards to solve word problems relating to area and perimeter.	The mobile device facilitated ways to visualise area and perimeter and off-loaded the computational task from the student. However, this only falls under *augmentation* on the SAMR spectrum as the mobile activities were merely enhancements of the paper version.
Session 7 (Area and Perimeter; Symmetry)	Using Area and Perimeter, a math manipulative application, students work in pairs and look for the 12 different shapes that make up a pentomino, identify its line of symmetry, area and perimeter.	Students worked in pairs and looked for the 12 different shapes that make up a pentomino, identified its line of symmetry, area and perimeter.	By the same rationale given for the area and perimeter sessions, this activity falls under *augmentation* on the SAMR model.
Session 8 (Symmetry, Angles, Area and Perimeter)	Following a scavenger hunt theme, students used Snapshot Bingo to look for objects in their environment that represented specific geometric properties. These gathered artefacts were later presented to the rest of the class.	Following a scavenger hunt theme, students looked for objects in their environment that contained specific geometric properties. The objects to look for were listed in a worksheet and students were tasked to draw or describe their findings. At the end of the session, the teacher called on a few students to give examples of what they found.	The technology in this instance facilitated data gathering which enabled the sharing session that was done in class. Based on the images presented, it was easy to identify whether these were right or wrong. For the control group, because they were limited to describing and drawing, if what they found was outside the classroom wall, it was not possible to verify whether it was a correct representation or not. And so, this activity is classified as *modification* on the SAMR hierarchy.

2.3 Research design

The study was a randomised controlled trial design using the M3 level evaluation framework. Table 2 below outlines how the data was collected for each level of evaluation. Table 2.

M3 Evaluation framework

M3 Level and Purpose	Instrument	Participants
Micro-level Evaluate student perceptions about each activity	End activity evaluation	Experimental and control group
Meso-level Evaluate student experience	Group interviews Teacher interview	Experimental group only
Macro-level Evaluate the effect of mobile use to students' performance	Math test	Experimental and control group

2.4 Instruments and measures

2.4.1 Technology used.

Mobile devices used in the study were 7-inch tablets of different makes and models. All tablets were Android 4.2 tablets costing less than £100 each. Because several activities were carried out while students moved around, the small form factor allowed mobility and the medium screen size allowed screen sharing.

2.4.3 Math test

The test had three topics: symmetry, angles and area and perimeter. These items were from practice exercises in Grade 5 and 6 mathematics textbooks used in Scotland (Heinemann Maths and TeeJay CfE Maths). Some test items on student misconceptions (Harris, 2000; Hansen, 2014) on each of the topics were added to the test to check whether the hands-on nature of the activities addressed common errors in the topics covered. As an additional validity measure, a mathematics teacher with more than 10 years of teaching experience checked the content of the test.

2.4.4. End activity evaluation

The End Activity Evaluation was adapted from two established usability questionnaires. Eighteen adjectives from the Microsoft Desirability Toolkit (Benedek and Miner, 2002) were arranged on a semantic differential scale five units apart with two opposite adjectives at each end. This resulted in nine adjective pairs. Additionally, two questions from the Lewis (1991) After Scenario Questionnaire were added to the instrument. The resulting questionnaire thus consisted of 11 questions with three factors of usability: usefulness, ease of use and user satisfaction (Lund, 2001). Table 3 lists some of the items from the survey and its corresponding category. Reliability of the instrument using 250 responses from a wider study was .757 for usefulness, .860 for ease of use and .880 for satisfaction. The instrument was administered to both the control and experimental group at the end of each topic by the teacher.

Table 3.

Items from end activity questionnaire grouped by scale

Scale	Cronbach's α	Items
Usefulness	.757	• Irrelevant vs Useful • Ineffective vs Effective
Usability or ease of use	.860	• Clear vs Confusing • Understandable vs Too Technical
User satisfaction	.880	• Satisfying vs Frustrating • Fun vs Boring

2.4.5 Interviews

Group interviews were designed to elicit student feedback about the activities which might have been missed in the end activity survey. Students reflected upon the activities that they had completed and were asked to explain which of the activities they liked and disliked. Their opinion on the advantages and disadvantages of doing these types of activities were sought. Students also related the challenges they had experienced with the activities. Discussions were audio recorded and transcribed.

A semi-structured teacher interview was also conducted. The teacher's view on the mobile learning activities, observations on how the activities affected the students and perceived advantages and disadvantages of mobile learning were sought. The interview was audio recorded and transcribed.

2.5 Procedure

All students completed the math achievement test at the start of the research project. To avoid confusion, the teacher read out the instrument to the students before having them fill out the form. The students were also encouraged to ask questions about any items they were not clear on. On the same day, following the tests, an introductory session with the experimental group was conducted to brief the participants about the nature of the activities to be carried out.

The control and experimental groups participated in eight 50-minute long sessions spread over a period of six weeks. This was originally planned for a two- month session but with a holiday approaching and the busy school schedule, this was cut to six weeks. So, during the last week, three sessions were delivered consecutively and the post-test followed the next day. The experimental group participated in activities that used tablet devices while the control group participated in activities of a similar nature but without the aid of mobile technologies (refer to Table 1). Students worked in pairs throughout the intervention and where possible with the same partner (unless their assigned partner was not present for the day). They participated in collaborative learning activities within the classroom and shared work area just outside the classroom. There were three topics covered (symmetry, angles, area and perimeter), with two sessions each. The last two sessions covered a combination of the previous topics. Both control and experimental groups completed an End Activity Evaluation questionnaire at the end of every topic. At the end of the programme, both groups took the math test. An interview with the teacher and student experimental participants was also carried out at the end.

2.6 Data analysis

For the micro evaluations, the scores in the adjective pairs were grouped into the three categories of usability: usefulness, ease of use and satisfaction and activity ratings, resulting in nine adjective pairs per category. The scores for each of the items in the group were averaged to obtain the usability score for the activity, yielding a score ranging between 0-5. The higher the score, the better the usability and vice versa. The usability ratings for each topic were compared between the experimental and control group using an independent t-test. Gender differences in the experimental group were also compared using an independent t-test.

The student and teacher interviews from the meso level data evaluations were analysed using theoretical thematic analysis. Theoretical thematic analysis is an analysis-driven thematic analysis as opposed to the more data-driven inductive approach (Braun and Clarke, 2008). The themes identified in the study closely matched the interview questions: 1) student perception of the tablet activities, 2) advantages of using the tablets and 3) disadvantages of using the tablets and 4) issues encountered. Responses were compared to the end interview data to see if there was a change in perception of the tablet use. The teacher interview was used to help validate the findings.

An analysis of covariance (ANCOVA) was conducted to test the difference in math achievement of the experimental group and control group before and after the intervention. The adjustment for pre-test score in ANCOVA ensures that the differences at post-test are not leftover differences between the groups and account for variation around the post-test means that comes from the variation in where the participants started at pre-test (Grace-Martin, 2013).

3. Results

3.1 Micro-evaluation

Figure 2 shows the end activity evaluation of the control and experimental group for each of the topics covered. Evaluation for the angles session was not conducted because of the students' busy schedule on that day. An independent t-test of the ratings for each of the subscales showed no significant difference between the two groups on all factors and all activities. Control children scored higher on symmetry and Area/Perimeter, while experimental children scored higher on Combined topics.

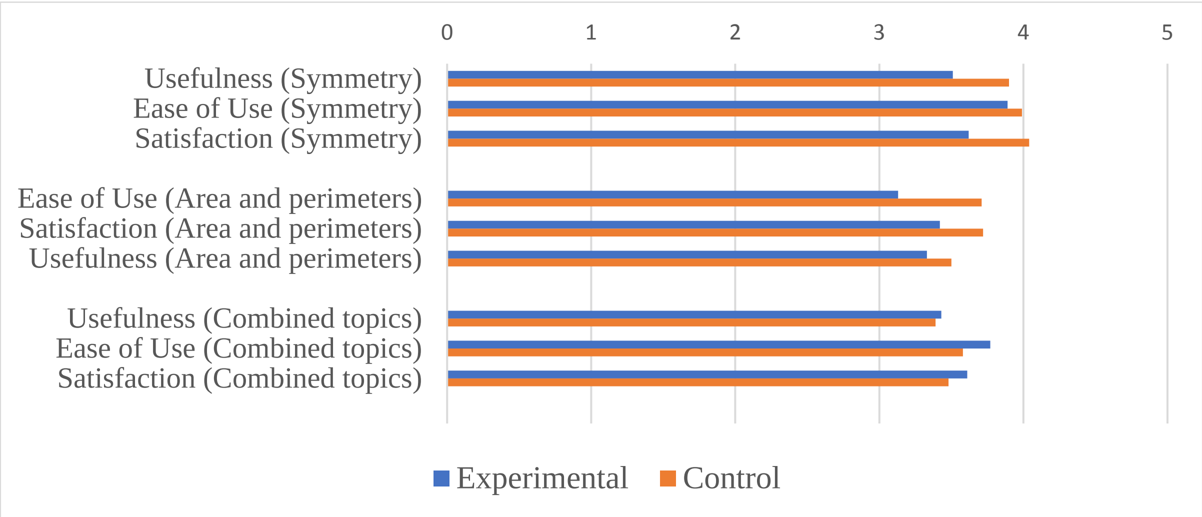

Figure 1. Usability ratings by activity

A comparison of the responses of male and female students in the experimental group showed that there was a significant difference between the boys' usability ratings and girls' ratings on almost all factors (Table 4). In all instances, the boys rated the activities higher than the girls, which can be interpreted as boys having more positive perceptions of the activity than the girls.

Table 4.

Usability evaluation by gender (experimental group)

	Group	N	Mean	Std. Deviation	p-value
Usefulness (Symmetry)	Male	18	4.17	0.64	**.000**
	Female	15	2.71	1.11	
Ease of Use (Symmetry)	Male	18	4.12	0.70	.065
	Female	15	3.62	0.82	
Satisfaction (Symmetry)	Male	18	4.10	0.77	**.003**
	Female	15	3.04	1.09	
Ease of Use (Area and perimeters)	Male	16	3.74	1.42	**.037**
	Female	14	2.44	1.84	
Satisfaction (Area and perimeters)	Male	16	3.83	0.98	**.049**
	Female	14	2.95	1.33	
Usefulness (Area and perimeters)	Male	16	3.69	1.17	.089
	Female	14	2.93	1.19	
Usefulness (Combined topics)	Male	17	4.20	0.69	**.001**
	Female	15	2.57	1.54	
Ease of Use (Combined topics)	Male	17	4.43	0.44	**.004**
	Female	15	3.03	1.54	
Satisfaction (Combined topics)	Male	17	3.99	0.80	**.045**
	Female	15	3.18	1.28	

Bold indicates statistically significant

3.2 Meso-evaluation

3.2.1 Student interviews

Thirty-one of the thirty-five students in the experimental group participated in the student interviews. Of the four students who didn’t participate, one elected not to be interviewed, while the three other students were not available on the day the interviews were carried out.

Twenty-four of the 31 (71%) students gave positive feedback about the intervention while the other nine (29%) students felt negative about it. Various numbers of students found the activities fun (n=14), interesting (n=4), easier (n=2) and preferable to their usual math (n=2). The activities were overall good (n=4), challenging (n=2), helpful (n=1) and novel (n=1). However, some felt that the traditional way of doing math was better (n=3). These students explained that they really didn’t get a lot from the intervention as it didn’t teach them anything new (n=2) and did not present enough challenges (n=1). They explained that it was boring (n=2) and at times even confusing (n=2).

An analysis of the feedback by gender showed some differences. Of the 19 male students interviewed, three students felt negative about the use of tablets while the rest were more positive about the intervention. For the female students, feedback was split evenly with 6 out of the 12 students (50%) not liking the intervention and the other half being more positive about it. One of the female students explained that she found the intervention “*quite confusing because it’s a lot of games and I find it hard because I don't really know a lot about technology*.”

One of the frequently mentioned advantages of doing the tablet-based activities was that it made learning fun (n=8) and consequently made them want to do it more. Another student explained that because it was fun, it made her understand the topic a bit more. Some students thought that it was easier (n=5) to do math with the tablets. This concept of being easier might be related to the process of traditional classroom math which is about drill and practice exercises. One student who discussed the activities with a student in the control group explained that the process of using the tablets in the walkabout activities made the activity a lot easier.

> *“When I went next door (control group) what they were doing was so hard and I think what we did was easier and they were saying we did it but the tablets make it easier coz they were doing it on paper[in reference to the control group’s activity where students have to draw objects that fit certain geometric properties].”*

The other advantage of using the tablets with math was because of the opportunity to use technology (n=6), but again this was more on the line of using technology compared to working with jotters. One student explained that an advantage to using technology with math was because he was used to using technology and this confidence to use technology consequently made him more confident with math. Some students appeared to have a negative attitude towards jotters and having to write things down (n=5), so the use of the tablets was a break from that usual activity. Students explained that the mobile supported activities were a lot more active (n=2) than their normal math lesson. A student explained, "*it's a lot more active and it makes you think a lot more than just sitting down and writing down on a piece of paper.*" A couple of students, however, did not see any advantage of using mobile technologies (n=2), noting their preference for jotters and learning with a teacher.

As for the disadvantages of using technology, some students thought that it could be a distraction (n=5) during math class, referring to other students who did not listen because they were fiddling with the tablets. Students who were not positive about the use of the tablets (n=3) explained that the use of technology was a step back from learning, as it required knowing technology first before doing math.

> *"I just think it's a massive step back for your learning… So you've got the app, you need to learn how to control the tablet, you need to learn how to control the app and that."*

Other students felt that the disadvantage of using tablets was related to the technical issues that one could encounter (n=6). The instability of the applications used, for example, would sometimes make them lose some of their work and have to start all over.

Most of the students had negative views about working in pairs (7 girls and 5 boys), noting how it was difficult to work on just one tablet especially when they were in disagreement with their partner. Boys (n=8) saw working in pairs more positively than the girls (n=2). The majority of the boys enjoyed working in pairs whereas the majority of the girls saw it more negatively. One of the boys commented, *"I find it easier. They could help you and you could help them… I made a friend like that."* Some students note, however, that working with someone they didn't really know was difficult (n=4). One of the girls explained, *"I like working in pairs, working with new people, but I just think I work better alone or with my friends."*

To students who viewed working in pairs positively, they saw how working in pairs simplified some of the tasks. A student explained:

> *"I don't mind working with a partner because I struggle a bit with my work so it helps me to have someone who knows when I've made a mistake or not.*

This point of view was shared by other students who scored low (<50%) in the initial math test score (n=6). The other students who scored low claimed that they liked working in pairs (n=4) but didn't explain their reasons for it.

The idea of shared work, however, did not suit half of the students who scored low in the math test (n=8). They explained that they did not like having to work in pairs because they felt that they did not have a lot of chance to use the tablets because their partner was *"hogging the tablet coz she knew what everything was."* Students who scored high in the math test also had difficulty working in pairs (n=5), as they too experienced disagreement with their partner and finding the sharing of the tablet difficult.

In addition to the challenges of working with a partner, a few of the students mentioned some technical difficulties like unresponsiveness of the tablet (n=2), the stability of the application (n=7), network connectivity (n=2) and a battery issue. However, none of these technical issues caused a breakdown to the point that students were not able to participate. In most cases, the problems were resolved by exiting the application and logging back in. One student mentioned that the difficulty lay with the maths content and another student explained that the difficulty was more to do with knowing the technology.

> *"A lot of the technical difficulties were knowing what you're doing coz it's easier to just give you a pen and paper and write it all down but with the tablets you need to at least use one before you can get into it and start using them."*

Teacher interview. A semi-structured interview was carried out at the end of the study. The teacher had found the mobile learning activities good and interesting. She added that she'd "*love to use them again; it really captured the children and made them engaged.*" She noted that the use of the tablets could complement the students' written work, adding that the children needed a combination of both.

For the teacher, the walkabout activity (session 8) at the end worked very well as it allowed her to "*see all their learning at the end."* She added that she also thought the angles activity worked well because it allowed the students to *"visually see one in front of them rather than a representation on the white board."* As for the one that didn't work very well, it was the symmetry session.

> *"I thought it was great but I think it just had an effect because some of my children have done symmetry before so I think it was maybe too easy for some of mine and I don't know if they became disengaged because of it."*

Advantages of using the tablet were improved student engagement and visualisation of math concepts. For example, in the angle activity, the application used allowed the students to see angles rather than a representation of them. The teacher observed that it was particularly good for students who were less inclined to engage during normal math period.

> *"I noticed the difference in attitudes towards their learning. They normally really don't like math, disengaged, don't want to do it. You normally have to push them to do it. Whereas [with the tablet-based activities] they actually got on really well, really enjoyed it. They were saying to me that they were looking forward to tablet math."*

3.3 Macro-evaluation

Descriptive statistics are shown in Table 5. An analysis of covariance was conducted to test for the differences between the experimental group and control group with pre-test as covariate. Assumptions of normality and homogeneity of variances were met. There was no statistically significant difference in post-test scores between the experimental and control group, $F(1, 71) = 1.000$, $p = .321$, partial $\eta^2 = .014$. Some items in the math test aimed to measure student performance relating to common misconceptions on the topics covered. A paired t-test of student scores on these specific items showed that there was a significant improvement in the experimental group's performance for 3 out of 4 items relating to misconception on angles. For the control group, there was an improvement in one of the items.

Table 4.

Descriptive statistics of math test scores

	Pre-test		Post-test		Adjusted Scores (Post-test)	
	Mean	SD	Mean	SD	Mean	SE
Tablet	16.77	6.92	20.57	6.30	20.57	.64
Control	14.33	5.29	19.72	5.70	19.62	.68

4. Discussion

The results section presented the data according to the M3 level evaluation. This section discusses the answers to the research questions drawing from the different levels of evaluation carried out.

4.1.1 Student views on the use of mobile technologies for maths

Both the experimental and control groups had mostly positive perceptions about their respective activities. Students in the experimental group consistently rated the activities as innovative over being old-fashioned throughout the three end-activity evaluations carried out. The activities with the control group, despite being similar in nature, led to them rating the innovativeness of the activity on a declining score. This finding can be an indication of how the presence of technology changes student perception about the novelty of an activity. Novelty effect is a common theme in mobile learning studies (Baya'a and Daher, 2009; Rehm, Stan, Woldike and Vasilarou, 2015), but this is an issue that is difficult to avoid given the relative newness of mobile technologies.

While most responses in both end-activity evaluation and interviews were positive, there were students who had contrary views. Reasons cited for not liking the activities were sometimes related to the difficulty of the topic. Some students didn't like the sessions on area and perimeter because they found them confusing. Some students didn't like the session on symmetry because it was something they had already covered before. The control group, despite having covered the same topic on symmetry did not seem to have an issue with the repetition. Their activity ratings did not also raise issues relating to confusion on area and perimeter.

A possible explanation for the differences might be related to the interplay of novelty and topic difficulty. In the symmetry session, while the students in the experimental group viewed the use of mobile technology as innovative, the topic it was implemented on was too easy for the students, making the sessions seem more supplementary than a truly novel learning experience. In the area and perimeter sessions, while the use of mobile technology was novel, some students did not see the benefit of using mobile devices for the activity. Lessons on area and perimeter were deemed difficult anyway and the effect of the technology was to give an added layer of difficulty. The two sessions to cover exploration of the relationship between area and perimeter using virtual manipulatives on the tablet might not have been enough and might have caused confusion to some students rather than clarified the concepts. The last session, however, was different as the use of the mobile device was instrumental in doing the activities. In this example, the mobile device facilitated the gathering of artefacts that represent geometric properties. These gathered artefacts became discussion points in the classroom as students presented their findings to the rest of the class.

The TAM framework (Davis, 1989) suggests that perceived ease of use (PEOU) affects how the user perceives the usefulness of the system and users' overall attitudes towards the technology in question. This means that users are likely to consider a system useful if they think that the system is easy to use. The relationship between the ease of using the system and students' attitudes towards mobile technology was evidenced to some extent in the student narratives about mobile use. For example, a student who found the use of mobile technology cumbersome particularly when it failed as they had to re-do the activity found paper-based maths activities preferable. Another student who was not familiar with technology also preferred traditional activities over the mobile supported ones as she explained that it takes one more step in the learning process by having to learn the technology first before being able to do the maths. On the other hand, students who found the use of the tablets easy also had more positive views about using mobile technology, saying it was better than their normal maths as well as more fun and engaging. This is consistent with technology acceptance models (TAM) for mobile learning (Chang et al., 2012; Huang, Lin and Chang, 2007) that note a relationship between PEOU and PU.

Mobile learning activities that were perceived to be useful, easy to use and fun were likely to result into more positive perceptions about mobile learning. The relationship between these three variables to attitudes to mobile learning can serve as a design guideline for mobile learning sessions. If an application is useful but awkward to use, then users might not take to it very well. In the same way, if an application is useful and easy to use but the activities end up boring the students, then this would not be received very well.

Students explained that the mobile learning sessions were a good opportunity to learn maths while using technology. This sentiment is echoed in several mobile learning studies on mathematics (Franklin and Peng, 2008; Kim, 2011). The other reason for enjoyment is the active nature of the activities carried out outside the classroom. Previous mobile learning studies carried out in outdoor settings also had positive student reception (Kurti et al., 2008; Rehm et al., 2015; Bray and Tangney, 2016). For the current study, it is possible that in addition to the outdoor setting, it was the active nature of the activities that students appreciated. This was discussed in the student interviews, and students explained that the activities were better as opposed to "*just taking it all in*" or "*just writing it on a jotter*". The mobile learning sessions were also perceived to be useful tools for visualising mathematics. The use of technology to aid in visualisation of maths concepts is embedded in mathematics education literature (Lagrange, Artigue, Laborde and Trouche, 2003). Boaler, Chen, Williams, and Cordero (2016) posit that "*when students learn through visual approaches, mathematics changes for them, and they are given access to deep and new understandings*" (p.1). Some of the student narratives discussed how the process of being able to see angles as opposed to having the teacher explain/describe it was helpful. Studies that tried to facilitate a link between real-world and abstract maths yielded similar positive feedback (Baya'a and Daher, 2009; Sommerauer and Müller, 2014) to the current study.

There were a few negative perceptions about tablet use. In the end-activity evaluations, there were ratings that favoured the negative adjective. Some of the negative student perceptions were related to the topic being studied. When students found the topic boring or difficult, this was reflected in the end evaluation. When they encountered technical difficulties, they also rated the activities lower. The socio-cultural perspective of learning suggests that "learning is affected and modified by the tools used for learning" (Kearney et al., 2012, p. 1) and in the case of technical difficulties, students' learning is also likely to be affected.

In the student interviews, some students shared that they did not see the benefit of using the tablets given that they had already covered some of the content in the previous year. The design of technology-enhanced learning activities affects how students interact with the content (Chen, Star, Dede and Tutwiler, 2018). In studies that reported negative student perceptions of mobile learning, the activities failed to engage students and were one of the factors that consequently resulted in negative perceptions (Liu, 2007; Roberts and Vanska, 2011). Drawing on the theory of the Technology Acceptance Model (Davis, 1989), the three aspects of usability, ease of use, usefulness and satisfaction affected overall student perception about the mobile learning activities. When students found the activity enjoyable, their engagement was also higher. If they saw the benefit of doing the activity, then they were also likely to engage. However, when they become inundated with difficulties, be it technical, social or with the topic itself, then their overall views about the usefulness of mobile technology changed. This highlights the role of careful orchestration of the learning activity and the responsibility this puts on the teacher.

4.5 Student achievement and mathematics learning in mobile learning environments

Both control and experimental groups had significant changes in their pre and post-test scores indicating that student performance had improved under their respective treatments. A comparison of the treatment effect, however, showed no significant difference between the two groups. This means that the experimental group performed just as well as the control group. Given that the nature of the activities was the same both groups, this result is not very surprising. In principle, the set of learning activities for both groups followed the same teaching strategy of active experiential learning. In the SAMR (Puentadura, 2006) spectrum this would classify the use of technology in most of the activities either under the augmentation or the modification spectrum rather than the higher spectrum of re-definition.

Some sessions could be classified under the modification spectrum of the SAMR model and these were sessions where mobile technology proved more useful than the paper and pencil counterpart. For example, in the angles sessions, students observed angles in their environment, captured evidence of these then explored the properties of the angles they had captured. These learning activities showed a seamless process of exploration and investigation of maths concepts facilitated by the mobile technology. Using the mobile device, students captured representations of angles in their environment. They then went on to investigate these angles further by annotating the images taken and manipulating the images (for example, the process of pinching and zooming to compare angle measurement of a zoomed in picture vs. a zoomed-out image). They were then given an opportunity by the teacher to share these artefacts with the rest of the class. The control group, on the other hand was limited in the further investigation that they were able to do, as their output was limited to a description or a drawing of an object. While both groups followed a constructivist learning activity, the mobile device facilitated investigation across contexts as students did the artefact gathering outside the classroom and reflected on these artefacts through further investigations and formed mathematical conclusions from it. Thus, both the experimental and control did constructivist activities, but the activities of the experimental group were more constructivist. While the groups' overall achievement scores were not statistically significant, the experimental group performed better on items relating to misconception on angles. This can be interpreted as a sign that the mobile supported learning activities on the topic angles was effective.

Some students explained that the activities made them recall the topics better and helped them visualise the concepts being learned, as was the case in other mobile learning studies

(Baya'a and Daher 2009). Chen et al. (2018) suggests that students' experience of technology makes a difference in student learning outcomes. Videos, animations and maths manipulatives are typical mediums that are used to help visualise maths concepts, both in mobile learning environments and computer-based environments. However, with mobile devices, an additional medium for visualisation is the learners' environment, facilitating a connection between abstract maths concepts and the real world. Some students felt that this new way of doing maths had helped them grasp abstract maths concepts and as a result helped them remember better. These narratives were supported by the significant improvement of the experimental group in the items related to common misconceptions.

Context is a key concept in mobile learning research. Mobile learning studies on maths that attempted to link classroom mathematics to real world maths had positive results in student achievement (Shih et al., 2012; Wu et al., 2006), as was the case in the current study. The literature of maths and technology maintains that context is an important factor in adopting technology in the mathematics classroom (Li and Ma, 2010). In fact, the change in attitude and improvement in student performance comes from not only embedding technology but also the "embedded method of teaching developed from the pedagogical reform (ibid, p. 219)." For this study, it is difficult to ascertain how the incorporation of the outdoor space, the collaborative nature of the activity or the students' perception of the activities contributed to the difference in the gains between the experimental and control group. However, it is also worth noting that these enshrine the potential of mobile technologies: to facilitate learning across contexts and provide personal and collaborative learning environments (Cochrane, 2010).

The mobile devices in this study supported constructivist learning activities through a process of learning by doing in a collaborative environment. While the control group was also able to conduct constructivist learning activities, the experimental group could be considered to be **more** constructivist. The mobile device facilitated the constructivist and collaborative activities carried out as students gathered artefacts that contained geometric representations from their environment. Students then moved to a more formal learning context and carried out further reflection and investigation on the artefacts they had gathered. These artefacts and creations became discussion points enabling the covering of topics from the standard maths curriculum. This process illustrates Crompton's (2013) definition of mobile learning which is "learning across context, through social and content interaction, using personal electronic devices (p. 4)."

The multimodality, portability and multi-functionality of the mobile device facilitated a variety of learning goals, from more active and situated learning activities to more reflective classroom-based activities. The networked devices facilitated sharing of students' works wirelessly between devices or tethered to the class's bigger screen. Admittedly, it did not always work, but at times that it did not the portable nature of the devices allowed sharing ~~students~~ work simply by passing it on to another group. The process of finding concrete representations of abstract maths within the environment facilitated a personal learning environment as the students worked on their own devices. These learning scenarios map to Carpenter and Lehrer's (1999) five activities that promote mathematical understanding: constructing relationships, extending and applying mathematical knowledge, reflecting about experiences, articulating what one knows, and making mathematical knowledge one's own.

4.6 Limitations of this Study

Several limitations were present in this study. While this study had a control group that closely followed the same activities as the experimental group, data gathered from the control group was limited to the activity evaluation, their attitudes to maths and their performance in a maths test. This could have been improved had they been interviewed or observed as well, to allow a finer contrast between the two groups.

Another limitation of the study is the duration of the programme. This study had six weeks between pre- and post-test, with one of the weeks having three consecutive mobile learning sessions. It is possible that a more intensive programme might have had better results, as the students lacked opportunities to become more accustomed to the technology. This leads on to the next limitation - the timing of the study and why the programme had to be cut short. The study started in the last week of October, close to the Christmas holidays. Schools are typically busy with extracurricular activities around December, as was the case here. So, it is possible that students might have been less focused than at other times of year, which in turn might have affected the results.

The random grouping is yet another limitation of the current study. By dividing the three classes into experimental and control groups, this led to an oversubscribed experimental group which affected the student pairings. Some students were paired with students that they did not normally interact with and this created some tensions. Gender and level assignments for the pairings were discussed in the interviews and might have affected students overall learning experience.

Due to practical constraints, the present study is limited by small sample size, relatively short duration of the intervention and the use of adapted instruments. It is recommended that future research focuses on longer interventions that follow a more integrated approach in embedding technology use. This can be achieved through closer working with teachers when designing the learning activities.

5. Conclusion

This study set out to investigate the effects of using tablet devices for mathematics learning in indoor and outdoor environments in terms of student perceptions and achievement. The M3-Level evaluation framework was used to evaluate the mobile learning intervention, utilising different instruments to analyse usability, learning experience and impact of technology use. This approach enabled triangulation and provided different levels of granularity in the investigation of the effects of using mobile technologies in the classroom. Student evaluations of the activities were positive for both groups but there were gender differences in student perceptions about tablet use. The intervention also saw significant improvement in performance for both groups, but there was no difference observed in the groups' performance at post-test, indicating that there was no significant treatment effect. However, the experimental group had higher scores on items relating to misconceptions on angles. While there are advantages in adopting these technologies in the classroom, it is worth emphasising how the design of the activities, the technical breakdowns and learner characteristics can make a difference in results. Similarly, it is important to consider the functionalities of the device and how it can be used to integrate into the existing curriculum. It is also important to consider how the design of the activities fits with learner characteristics. Interaction with technology should be driven by the learning tasks, rather than technology driving the learning activity. This shows the onerous responsibility that teachers have in driving successful mobile learning interventions and the need for continued teacher training, support and time to develop the confidence and the skill in using novel learning technologies.

The mobile learning experiences facilitated active learning activities in math – they facilitated investigation and forming connections between abstract math and concrete representations in the environment. In these activities, there was a shift in the teacher's role and responsibility, from the person guiding and stimulating discussion to that of a "curator—a collector, organizer and guarantor of educational opportunities" (Crompton and Traxler

2015, p.230). As such, it would be worthwhile addressing how teachers are being trained to target those issues as well as being trained to use new technologies.

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